Report of the C-AD Machine Advisory Committee Meeting

8-10 December 2014

1. *Executive Summary*

This meeting of the MAC focused on three main themes:

Current status and plans for RHIC. The performance in recent runs has reached new heights, both for polarized protons and heavy ions, in a wide variety of energy and species combinations. A convincing strategy to sustain and extend this, in the service of a physics program continuing for several years, was presented.

The MAC warmly congratulates the staff of the C-AD for these outstanding achievements which will stand as high points in the history of particle colliders.

The Low energy electron cooling (LEReC) project should enhance the low-energy heavy-ion luminosity in the quest to explore the QCD phase diagram. Although electron cooling has been applied in numerous machines, this is by far the most ambitious application to date and must demonstrate several innovations.

Proof-of-principle test of Coherent Electron Cooling (CeC). This new cooling concept is an important component of the current version of the eRHIC design for an electron-ion collider and holds the promise of high cooling rates for high-energy hadron beams that are out of reach of established cooling techniques. The many subtleties in the mechanism will require much experimental R&D of which this is a first and crucial stage.

2. *Welcome, Response to last MAC's Recommendations*

Findings

The 2013 MAC provided a long list of recommendations. The report conscientiously addressed every one, though in a few cases with “to be done”. As a response to the recommendation to “develop a performance risk mitigation strategy” this was unduly modest, since much of the present review amounted to developing just such material.

Ongoing simulation studies have identified no serious depolarization problems though investigation of depolarization while passing close to the beam separation septum has begun only recently. Beam loss due to Touschek and beam-gas scattering has been found to be acceptably small but beam loss due to nonlinear effects in the FFAG arcs remains uncertain.

Concerning the SRF-ERL, Committee recommendations to refine HOM studies, to investigate electropolishing and operation temperature have continued, but have been superseded by issues discussed in detail in other presentations.

Several of the committed recommendations could be reduced to requesting refined simulation. A year ago the ZGOUBI simulation was already useful. Developments since then were not presented.

Impressive orbit correction of misalignment and gradient errors simulation was presented, even in the presence of chromatic effects and multiple passes through the same BPMs. Dispersion effects are under study.

Committee recommendations concerning magnet design were somewhat premature, in that detailed design had not yet begun. A more basic issue, namely the fundamental design concept including the possibility of incorporating permanent magnetic material into the design, had not yet been fixed, and remains to be determined. The choice between pole-dominated hybrid and coil-dominated Halbach designs remains open.

Some of last year's questions concerning electron cooling were discussed in detail at this year's MAC meeting and are reviewed in other sections of this report.

Simulation code has now incorporated ion instability sensitivity. Other collective effect questions of a more speculative nature, such as resistive wall, two bunch head-tail, and beam-beam influence on beam break up have not yet been addressed.

An extremely ingenious interaction region (IR) design was presented and discussed at some length. The essential idea reduces the beam crossing angle by threading the electron beam pipe through a region of the hadron beam magnet coil at which the magnetic field nearly vanishes. By means of special purpose coils wound on the electron beam tube, the magnetic field can be tuned accurately to zero on the electron beam orbit.

Achromatic IR optics have been investigated using DA (differential algebra) optimization to obtain 20σ dynamic aperture up to 0.15% energy deviation. Crab crossing optics and reduced β^* design remains to be done. Beam-beam experiments to be performed following the CeC test have been discussed.

This 2014 MAC meeting was not intended to review FFAG lattice design issues, so there was not a detailed report at this meeting. But there was mention of preliminary discussions concerning the possibility of collaborating with Cornell University to build an FFAG prototype ring at the Cornell Wilson Lab.

Other eRHIC R&D efforts are progressing. Tests of the Gatling gun polarized source are in preparation. High gradient crab cavity development is proceeding within the LARP collaboration, with testing to be done at SPS. Also a polarized He-3 source is being developed in collaboration with MIT.

Comments

Outstanding issues include beam cooling, FFAG electron lattice optics and IR magnet design.

The possible prototype FFAG test at Cornell would answer (more persuasively than can be done theoretically) many of the questions brought up at the 2013 MAC meeting. However it would be important to execute it in a timely fashion.

Recommendations

- A thorough update on the eRHIC design will be appropriate at the next MAC meeting. It should include more detailed simulation, especially concerning nonlinear beam loss effects in the FFAG, as well as updating beam-cooling progress.
- Report on magnet development, including IR design and FFAG electron ring, hybrid vs Halbach designs, including field quality issues, and permanent magnet advantages and disadvantages.
- Report on IR achromatic optics design including crab cavity design.
- The committee believes that it is important to carry out a prototype FFAG test in the context of a detailed roadmap towards eRHIC.

3. *RHIC Status and Run Plans, Ultimate Au+Au Luminosity*

Findings

In FY 2013, the RHIC collider provided over 460 pb^{-1} of integrated luminosity in (up to 57%) spin-polarized proton-proton collisions at $\sqrt{s} = 500\ \mathrm{GeV}$. In part of the FY 2014 run, it provided over 140 nb^{-1} (nucleus-nucleus) in Au-Au collisions at $\sqrt{s_{NN}} = 200\ \mathrm{GeV}$.

In addition, the FY 2014 run included an additional two operational modes, with Au-Au collisions at $\sqrt{s_{NN}} = 14.6\ \mathrm{GeV}$, the final part of Beam Energy Scan 1, in the search for the QCD critical point, and the first collisions of He-Au nuclei at $\sqrt{s_{NN}} = 200\ \mathrm{GeV}$.

Performance gains have come from a diverse range of improvements to the RHIC collider and its injector complex. For example, the polarized proton operation benefitted from the new atomic beam polarized source and the Au-Au low energy operation from AGS extraction below transition. The high energy Au-Au operation benefits from the laser-ion source and EBIS. The full 3D stochastic cooling allows more of the injected intensity beam to be converted into integrated luminosity more quickly. The now complete scrubbing of the vacuum chamber by the proton beams has eliminated heavy-ion losses at transition.

The beam parameters (intensity, emittance…) and luminosity during the store can be predicted with good accuracy with the present simulation codes (including burn-off, IBS, cooling and other effects). This method has been used to successfully select which upgrade projects are advantageous.

It is worth noting that the stochastic cooling has also increased performance in indirect ways by shifting the traditional imperatives of hadron collider operation. For example, it is no longer so important to avoid beam instabilities that might increase emittance in the ramp.

Continuing improvements in overall reliability of the RHIC complex and implementations of beam-based feedback have also translated into higher operational efficiency and reduced set-up times.

The He-Au collisions depended on new bunch-merging techniques in the AGS and operation of RHIC with large orbit excursions.

Comments

The integrated luminosities achieved in each of principal high energy operating modes in FY 2013 and 2014 exceeded the combined totals from all previous runs of RHIC in the same modes. These remarkable results are unique in the history of hadron colliders (no other machine has operated in such a diversity of modes). They are the fruit of a long series of innovative and cost-effective upgrades and amount to having economically achieved the performance levels of the former “RHIC II” luminosity upgrade program.

The scientific goals of the RHIC program in the coming years nevertheless present further challenges with multiples species combinations at both low and high energies. The major upgrade still to be demonstrated is the low energy electron cooling (LEReC) required for Beam Energy Scan 2. However the plans to approach the ultimate Au-Au luminosity, where all stored ions end up colliding (full “burn-off”), in high-energy operation require some new development as well as further development of techniques already commissioned. Among these, the 9 MHz cavities, the 56 MHz cavities, the OPPIS, electron lenses and luminosity levelling with variable β^*, to match the luminosity delivery to the useful event rate limits of the experiments, will be important.

The integrated luminosity in RHIC is largely determined by the bunch intensity. To increase the bunch intensity, and therefore the integrated luminosity, the laser ion source is being modified for a potential gain in injector current of order 20%. On the other hand, electron capture still seems to be a major component of the 30% losses in the AGS Booster. Since beam loss by charge exchange is intensity-dependent, a potential increase of injector current may even lead to a reduced transmission though the AGS Booster. Looking at the extracted bunch intensity of a subsequent chain of AGS booster cycles indicates a slight decrease, potentially due to a degradation of the residual gas pressure.

Recommendations

- In order to minimize beam loss from charge-exchange, modifications of the AGS Booster vacuum system, preferably around the injection and extraction systems should be considered.
- It was stated that the available time for accelerator-physics experiments (APEX) could easily be taken up by studies related to coherent electron-cooling. The committee sees this as undesirable and recommends that an essential minimum be kept available for developments related to the more immediate performance of RHIC.
- If any APEX studies could increase the chance of early LEReC success, then they should be encouraged.

4. *Overview of Low-Energy RHIC electron Cooling (LEReC)*

Findings

LEReC is organized as an Accelerator Improvement Project and is supported primarily by the C-AD. The cooler is scheduled to be operational in FY18 (Phase I) and FY19 (Phase II). The main difference between the two phases is associated with the electron beam energy: 2 MeV and 5 MeV correspondingly. To cover all RHIC ion energies of interest, the electron cooling system should work in the 0.9-5 MeV (kinetic) electron beam energy range. It has been noted that, at low energies in RHIC, the luminosity has a very fast drop with energy (from γ^3 to γ^6). As a result, the achievable luminosity becomes extremely low for the lowest energy points of interest. The quantitative goal for the luminosity improvement from the electron cooling system is expected to be a factor of 4 in Phase I and up to a factor of 10 in Phase II. In Phase II the cooler will operate in an ERL mode.

High-priority items are already approved by the DOE for procurement (cooling sections elements and a new 704 MHz laser which will be commissioned in the ERL building with the SRF gun). The goal is to install cooling sections in RHIC already by the end of 2015.

The schedule shows the installation of the LEReC accelerator and transport lines in the RHIC tunnel starting July 2016. However, the schedule is very tight and constrained.

The scheduled project early finish date is September 2017, which would allow commissioning for the physics run to be started in 2018. The project critical path is presently driven by the SRF gun development. This gun was scheduled to be commissioned in Dec 2014. However, it is clear that this milestone will not be achieved. The parallel development of a DC gun has started and is supported by the committee.

Comments

We congratulate the team on obtaining the first beam from the SRF gun. The team is strong and work on this project is essential for pursuing exciting physics goals in RHIC.

The LEReC project is of priority for the C-AD, yet the schedule is very aggressive and the resources are quite constrained by both the manpower and by the AIP spending limit.

Recommendations

- Determine from beam simulations what is the highest electron beam current one can operate at without cooling section solenoids being on. Ensure that the beam diagnostics are capable of operating at such current. This might be the current used for the commissioning process.
- Appoint a single point of contact for the Machine Protection System. Analyze potential catastrophic events (such as loss of vacuum in the electron beam line) and interface to the RHIC MPS to analyze impacts of such events on RHIC.

5. *SRF Gun Commissioning Progress*

Findings

The SRF gun for LEReC has in commissioning from November 2012 to December 2014. The SRF gun was demonstrated to operate at 2.0 MV CW with an amplitude stability of 2.3×10^{-4} RMS and a phase stability of 0.035°. The cathode stalk has been inserted and the SRF gun operated. Early results showed multipacting with the stalk. The stalk was then rebuilt and re-tested, proving to be multipacting-free. The stalk is inserted under vacuum with a long insertion rod and interchangeable cathode pucks. The cavity vacuum has remained excellent during the cathode changes. Only three vacuum trips with cavity field were needed to condition the cavity with cathode to 1.2 MV field at 20 ms pulse. The cathode stalk has a Ta tip with CsK_2Sb coating for high quantum efficiency (QE) operation. In November-December 2014 the SRF gun was operated with first photoemission and initial beam parameters measured. The recent beam tests are aimed at satisfying the conditions for DOE approval of “Commissioning Accelerator Safety Envelope Credited Controls and Supports for ERL low power testing.” The recent measurements have concentrated on pulse duration, beam current measurements, and bunch charge. The bunch charge is 1.7 pC, with a current of 2.4 nA. The quantum efficiency is 1.2×10^{-5}. The spot shape has been observed on a profile monitor. The dark current was measured to be about 1 μA.

The long term goal is to commission the gun with full charge of 300 pC per bunch and a CW average beam current of 50 mA.

Comments

The commissioning results so far are encouraging although much work remains to be done. The produced bunch charges will need to be increased significantly to approach the design requirements. The beam emittances and energy spread are crucial for making the electron cooling work well. Completing the needed diagnostics for full beam measurements is also important as are measurements of all beam parameters at high charges and currents.

The energy spread measurement is based on the dipole magnet, which has an accuracy of about 1×10^{-3}. However, the goal is 10^{-4}. The measurement technical strategy for this tighter tolerance should be made clearer.

In order to make the specified time line for RHIC physics, there is essentially no time float remaining. Thus, the RHIC project must make sure that, going forward, the SRF gun program stays on schedule and attains its performance goals.

The SRF gun performance parameters must not only be achieved but also sustained for regular long-term operation.

Recommendations

- Increase the produced bunch charges from the SRF gun toward the design values as soon as is reasonable.
- Measure the beam emittances and energy spread versus bunch charge as soon as is reasonable.
- Establish a set of technical milestones that will allow the choice between the SRF and the DC guns to be made about a year from now.
- Demonstrate 24/7 operation at full specification of the SRF gun.

6. *LEReC: Beam Dynamics Simulations with DC Gun*

Findings

Low energy RHIC electron beam dynamics simulation studies were described, with emphasis on investigating the possibility of using a DC gun as a fallback, replacing the 704 MHz superconducting, SRF gun. Most dynamic investigations, performed primarily with PARMELA, are concerned with beam evolution following the gun, and might be expected to be unaffected by this change. But hardware realities have violated this equivalence to some extent.

In spite of the hardware differences, the subsequent beam evolution, including bunch stretching in the 700MHz RF cavity and linearization in the third harmonic cavity appear to proceed equivalently with the SRF and DC guns. One source of uncertainty is a possible difference in energy spread of the SRF and DC guns. Starting from $\delta p/p = 0.005$ in the SRF gun, after bunch lengthening the momentum spread decreases to $\delta p/p = 0.0005$ into the electron cooling region.

On the other hand, the front end value of the DC gun momentum spread was feared to be significantly larger in the DC gun than in the SRF gun. But, according to the publication of Gulliford et al., PRST-AB 16, 073401 (2013), describing the performance of the Cornell DC gun, the fractional momentum spread is in the range $\delta p/p = 0.001\text{-}0.002$, along with normalized emittances of approximately 0.7 μm in 77 pC beam bunches. Taken together these values are consistent with low energy cooling, with SRF and DC guns being more or less equivalent.

At a preliminary theoretical level, therefore, the low energy electron cooling process seems to be well understood.

Comments

The simulation is somewhat idealized and over-simplified, e.g., round beam approach rather than realistic initial distribution, lack of error analysis, no non-linearities in magnets, no fringe fields, no interaction with hadron beam.

Recommendations

- For further refinement of low energy electron cooling, the choice between SRF and DC guns should be made in the near future.
- Improve the simulation by addressing the deficiencies mentioned above and possibly adopting another simulation code.

7. *LEReC: System Engineering Design, Construction, and Installation*

Findings

The status of design, procurement and planning for preparing the installation of the components of the LEReC in the interaction region 2 has been presented.

With respect to the installation and integration of components, relative to each other and relative to the building, a detailed 3D model has been set-up.

For implementing the existing RHIC components, the available 2D AUTOCAD drawings have been established as a 3D model in Pro E.

For quality assurance the engineering groups involved use component and drawing data bases.

All changes with respect to the present set-up follow a formalized change management program and decision-taking and approval processes are established (e.g., regular meeting of the Warm Change Committee meeting).

The exchange of models and drawings with external suppliers has been standardized by using STEP format. The exchange of STEP files involves a certain loss of attributes and requires manual implementation into the existing drawing data base.

Beside the refurbishment of an annex building, no major modifications are required concerning the existing tunnel and buildings

The schedule for the procurement of the main components seems challenging and allows no major delays.

Comments

The committee recognizes and supports the challenging but still feasible procurement and installation schedule. The critical path for the overall facility commissioning is the availability of a tested and functional electron source. In order to achieve the required low angular tilt between the electron and the hadron beam a careful alignment concept, considering all potential errors and tolerances has to be established.

A potential difficulty may be the knowledge of the magnetic field axis of the solenoids with respect to the fiducials and a potential movement of the magnetic axis for different excitations. The intrinsic geometrical error, given by the distance of the solenoids and correctors, of the angular mismatch between electron and hadron beam may be 300 μrad which seems too high. With respect to the measurement of the position of the electron and hadron beam position by means of BPMs, the frequency and amplitude response must be considered.

Recommendations

- With respect to the available resources, the installation and commissioning of components for LEReC may be in competition with the set-up of the CeC PoP experiment. In order to avoid delays, an early prioritization should be done by the management for the case of conflicts.
- The magnetic field axis of the solenoid magnets must be perfectly aligned with respect to the hadron and electron beams. Consider aligning the solenoids with respect to the measured position of the hadron beam (which requires a transfer of the field measurement to the fiducials) and positioning the electron beam with respect to both in a second step. The Committee has proposed making extensive use of Hall or NMR probes especially to control the integral field strength in the 180° dipole magnet. Furthermore the Committee suggests following-up tightly the magnet field measurements and fiducialization at the manufacturer's site and to carefully specify the measurement technique and tools for the field measurements.

8. *LEReC: SRF and Warm RF Components*

Findings

Components

There are five RF systems in LEReC: the 704 MHz SRF gun and 5-cell SRF cavity; a 9 MHz buncher cavity; new 704 MHz and 2.1 GHz warm cavities.

The SRF gun commissioning with high beam currents in CW mode will have to be completed in Building 912: new cathodes; improved cathode cooling; new HTS solenoid leads. The gun's FPC coupling will be modified using 3-stub waveguide transformers.

For the parallel path with the DC gun, the gun SRF cavity can be converted into a booster cavity.

The 5-cell cavity is ready for LEReC but needs to be relocated.

A complete 9 MHz buncher cavity system, available from RHIC, will be used for beam-loading compensation.

A new single cell 704 MHz warm cavity will be designed and ordered from industry. Its RF design is in progress and will be completed in December. There are a number of companies that can manufacture the cavity. The RF window will be built according to JLab's specifications in collaboration with R. Rimmer.

RF design of the new 3-cell third harmonic cavity operating at 2.1 GHz is complete. Mechanical design is in progress. The cavity can be fabricated by industry or in collaboration with a national lab.

Timeline

FY2015: continue commissioning of the SRF gun; finish RF and mechanical design of the 704 MHz warm cavity, engineering design review, place orders for the cavity, RF window and other RF components; finish mechanical design of the 2.1 GHz cavity, engineering design review, place orders for the 2.1 GHz cavity, FPC, RF amplifiers, other RF components.

FY2016: receive and inspect components; high-current commissioning of the SRF gun and 5-cell cavity in CW mode (Building 912); modification of the gun into a booster cavity if necessary.

FY2017: installation in IR2, commissioning.
FY2018: commissioning with RHIC beams and low energy Au operation.

Comments

The SRF gun has to be improved to meet the project requirement. The cavity is used to provide an energy spread along the bunch for bunch lengthening with an accelerating voltage of 0.155 MV for LEReC-I (~0.16 MV/m) and 3MV (~3MV/m) for LEReC-II in the ERL configuration. The SRF 5-cell cavity reached 11.5 MV/m in the cryomodule with enough margin for these goals. The SRF 5-cell cavity presents low risk. The 2.1GHz normal conducting cavity is in a design stage. The fabrication and demonstration are urgent issues.

Recommendations

- Pursue the DC gun collaboration agreement with Cornell. Double-check the interface between the SRF and the DC guns to make sure that the SRF gun cavity does in fact need to be reversed to accommodate the DC gun.
- Include longitudinal wake fields (the cavity loss factor) into calculations of electron bunch energy spreads as well as the bunch-to-bunch energy spreads.

9. *LEREC: Instrumentation*

Findings

The effectiveness of the electron cooling process depends critically on precise knowledge of the electron beam parameters and, to a lesser extent, those of the heavy ion beam. In some instances, the precision required is very demanding. In particular, the energies, time structures, orbits and transverse dimensions of the electron and ion beams have to be carefully matched. The cooling rate depends on the inverse cube of the energy spread of the electron beam, which has to be $< 5\times10^{-4}$ and known to within 1%.

A comprehensive and systematic approach to instrumentation of the LEReC beam lines was presented. Many of the required systems have been specified and fully designed. However a significant number are still under development and some problematic cases currently appear to be high risk items.

A number of beam instrumentation items from the Prototype ERL.are being re-used.

Comments

The measurement of most beam parameters of the ion beams in the RHIC rings is well in hand. In particular it should be possible to monitor the cooling of the emittance. However, in the cooling section, the measurement of the orbits of both beams with common pickups presents some special challenges which are being addressed.

Verifying the energy matching via the measurement of recombination radiation is an attractive idea, particularly in the absence of localized losses of the modified ions, but needs to be fully worked out. The committee has some concerns about the difficulty of tuning the energies to match. Separate absolute energy measurements of the two beams would be ideal.

The measurement of the energy spread in the electron beam with YAG scintillator screens in dispersive sections is insufficiently accurate and alternatives such as the Cornell deflecting cavity or a dedicated spectrometer are more costly and complicated.

The photo-multiplier tubes (PMTs) used as beam loss monitors may be affected by radiation from the beam dump. Given the damage potential of the electron beam, this is a concern.

The CCD cameras as presently foreseen are not gated and are incapable of measuring the bunch structure within the macro-pulses. Thus potential transient effects, e.g. at the beginning of the macro pulses cannot be observed. Different bunch intensities or bunch to bunch intensity fluctuations in the first of the RHIC rings may influence the beam dynamics of the electrons and consequently change the electron beam properties in the other ring. This should be observed, e.g., by measuring the electron beam parameters after the 180° bend with and without beam on. In any case a cross talk between both rings via the electron beam has to be avoided.

Recommendations

- Evaluate alternative methods for measuring the problematic key performance parameters with high priority.
- Make sure that the diagnostics in the cooling section (e.g. BPMs) can detect both the ion and the electron beam. One can rely on the ion beam orbit as a reference orbit to adjust the electron orbit.
- Start planning for measuring the absolute energies of electron and ion beams. Also, plan on monitoring the electron and ion beam energy stability on-line as a diagnostic tool for cooling.
- Consider simulations to verify the adequacy of the beam-dump shielding.
- Review the machine protection strategy and its possible failure modes.
- Evaluate the possibilities (fast scintillators, gated CCD cameras, etc) with a view to developing a capability for resolving the time-structure of bunches within the macro pulses.
- Initial commissioning strategies of the cooling system and reaching the correct beam parameters should be worked out in detail. As already mentioned, starting with the solenoids switched off may be helpful. In this context, the dynamic range of the instrumentation is important and should be specified clearly. The project should add the dynamic range of the measurement equipment to the table of requirements (min/max).

10. *Overview of Coherent electron Cooling Proof-of-Principle (CeC-PoP)*

Findings

A general overview of the CeC-PoP project was presented, indicating the key accelerator physics and layout aspects. The required goal for the ultimate use of CeC in eRHIC is to provide proton beam damping times of a few minutes. The CeC-PoP is a crucial step towards this goal. The goals are to demonstrate energy cooling, compare with theory and simulations, and cool the entire beam. These tests will indicate the next round of improvements, if any, needed for the full CeC design. The CeC-PoP configuration has additional capabilities to study effects of the beam-beam interaction, micro-bunching, and traditional e-cooling.

The differences between stochastic cooling and CeC were discussed with arguments for the strongly increased damping speed of CeC.

Comments

The theory for CeC is sufficiently complicated that the full details are understood by only a few staff. Numerical simulations have been done to replicate the analytic estimations and seem to agree to 10% or so in most parameters. These simulations should continue with more three dimensional calculations.

Simulations of the tolerances on errors in CeC-PoP that could be present in the installed accelerator should be continued including component mis-alignments, field strength errors, tuning errors, energy errors, and steering errors.

The implementation of CeC-PoP at RHIC uses many components from former BNL projects and a few new low-cost components and is, thus, a very cost effective experiment.

Recommendations

- Carry out an overall review of the (somewhat complicated) theoretical design of the presently envisioned CeC-PoP test with the help of external FEL experts to make sure it will work as planned and that nothing has been left out.
- Continue to carry out modeling studies of the cooling process with realistic ion bunch parameters in the time domain, including the IBS.
- Carry out cooling simulations with non-Gaussian electron bunches as seen and expected from the SRF gun
- Determine the observables for the initial set of experiments. Define a minimum set of observations to declare success.
- Initiate planning to measure the absolute energies of electron and ion beams.

11. *CeC: Photo-Injector*

Findings

The goal of the SRF cathode gun is 5 nC/bunch and 78 kHz repetition rate with beam.

The maximum energy is 2 MeV. The cavity is operated at 4K with $Q=1.8 \times 10^9$ at 14.5 MV/m on the cathode. The cavity RF loss is 17 W. The RF loss in the stalk is 38 W. Loaded Q is 1.25×10^7. The cavity frequency is 112 MHz.

There have been significant improvements in the quantum efficiency (QE) of multi-alkaline cathodes produced at BNL. The stalk and cathode cart system was installed and successfully used to install a cathode puck into the SRF cavity during the recent campaign of SRF cavity testing and conditioning. The cathode cart system commissioning is underway to ensure that cathodes with robust quantum efficiencies are reliably transferred from the cathode garage to the end of the stalk and back again.

Present planning foresees the SRF gun of the CeC PoP photo-injector system beginning operation during Run 15.

Comments

Bench observations of QE of 8.2–10.1% at room temperature are very impressive. These have been established by means of an UHV ~ $1x10^{-11}$ Torr and a very smooth cathode surface polished by diamond. Unfortunately this has not been demonstrated in the gun, nor has cathode longevity been shown. The cathode operation at room temperature (water cooling) is an excellent idea provided the SRF cavity performance is not affected.

The gold-plated stalk to reduce radiation is an innovation. The $\lambda/4$ choke structure and good RF contact are a very good design. The particle contamination has been sufficiently addressed.

Recommendations

- Adopt a robust cathode material with sufficient quantum efficiency.

12. *CeC: Overview of Construction Progress, Final Installation Planning*

Findings

(See also findings on LEReC System Engineering Design, Construction and Installation)

A rough schedule for the next steps towards a staged installation and commissioning has been presented. The overall installation and commissioning process has to be well synchronized with the set-up of the LEReC experiment. Since a limit for the overall costs has been set, several components were reused and refurbished. Because of delayed deliveries, the schedule originally envisaged has already been missed by one year. The most important milestone and, besides the availability of the 704 MHz 5 cell cavity, presumably the most critical item, is the commissioning of the 112 MHz electron gun envisaged in 2015. Apart from a few devices around the beam dump, the set-up has no major overlap with the planning and final installation of the LEReC project. However, several components are shared with the LEReC (e.g., the cryogenics system, diagnostics) so that parallel operation of both facilities is not feasible.

Comments

The PoP set-up allows cooling of only one bunch of the circulating Au bunch train in RHIC. Therefore, the Committee has questioned whether an integral measurement over all bunches, rather than a gated measurement bunch-by-bunch is adequate to demonstrate the effect of local cooling.

Recommendations

With respect to the available resources, the installation and commissioning of components for CeC PoP may be in competition with the set-up of the LEReC experiment. In order to avoid delays, an early prioritization should be made by the management for the case of conflicts.

13. *CeC: Theory/Simulations*

Findings

The committee heard a very dense presentation of the theoretical analysis of the CeC process, including the original scheme using an FEL as amplifier, operating in a linear regime well below saturation, and the more recent proposal using a micro-bunching amplifier.

Analytical models of the modulator, amplifier and kicker sections, with both cold and warm electron beams, have been developed and used to understand, compare and benchmark the simulations. Analysis of various effects potentially limiting the CeC process has not found any show-stoppers.

Recently, simulations at an external company had to be dropped because of funding limitations.

Comments

This presentation underlined the fact that the principles of CeC are quite complicated and subtle and effectively re-iterated the need for the proof-of-principle test.

The committee was somewhat disappointed to learn that, despite the elaborate theoretical and simulation framework presented, the simulation shown to illustrate the predicted result of the PoP was not recent and not based on a proper model of CeC (this was later remedied in part). The relationship to measurable signals of a cooling process was not clear. The observables at the CeC PoP have to be analyzed carefully; for example the emergence of high frequency content in the bunch spectrum could easily arise from other sources. This suggests that time-domain observables should be better indicators of a cooling process.

Recommendations

- Update the simulations of predicted cooling and diffusion in the Proof-of-Principle test and clarify the relation to experimental observables.
- Since the CeC-PoP will not test all aspects of the full CeC, specify clearly which essential physics and hardware aspects of CeC will be tested and which not.

14. *CeC: SRF and Warm RF Components*

Findings

Three SRF/RF systems are under construction for the CeC PoP experiment.

The 112 MHz quarter-wave resonator (QWR) SRF gun will provide a 2 MeV, high bunch charge (5 nC) electron beam. It is installed at IR2 and is under commissioning. So far the cavity reached ~2 MV in pulsed mode. Field emission and multipacting are limiting the voltage, further conditioning should improve the cavity performance. The loaded-*Q* (Q_L) of the 112MHz QWR is $1.25\text{x}10^7$, of which the bandwidth is only 9 Hz.

Two 500 MHz normal-conducting bunching cavities are on loan from Daresbury Laboratory as their contribution to the CeC PoP experiment. The cavities were refurbished and have undergone particulate-free assembly. The system is installed in the RHIC tunnel. Each cavity was conditioned individually, exceeding the required voltage (300 kV). Commissioning the system with the two cavities operating in parallel will begin soon.

The SRF cavity (BNL3) fabricated for the BNL ERL project will also be used. This 704 MHz 5-cell SRF cavity will boost the beam energy to 22 MeV. The band width of the cavity is 25 Hz and it is operated at 1.9 K in the CeC PoP.

This cavity was fabricated by AES and was successfully tested in a vertical test facility (VTF). The maximum gradient was 20 MV/m by administrative limitation (X-ray radiation). The cavity was then shipped to Niowave for the cryomodule assembly. The cavity helium vessel with an integrated superfluid heat exchanger is welded to the cavity and the assembly is at ANL for the final cavity treatment. The cryomodule delivery to BNL is expected in spring of 2015.

A 20 kW RF amplifier was ordered from SigmaPhi. The amplifier fabrication has been completed and the factory acceptance test is scheduled for mid-December. RF transmission line components will have to be ordered.

Comments

All three components already exist (704 5-cell is under cryomodule assembly at ANL). The SRF gun is not yet commissioned and is a technical risk.

Recommendations

- Push forward the commissioning of the SRF gun, monitor and report the progress.

15. *CeC: Diagnostics*

Findings

The full package of diagnostics for the CeC-PoP project was presented. The desired and expected resolutions for the various instruments were shown. This included diagnostics for CeC-PoP for the electron gun through the transport line, undulator system and to the dump, for RHIC with the hadron beam in the vicinity of the undulator, and for the FEL with the light from the undulators. Fully resolved signals and measurements from all these systems are planned to provide a complete knowledge of the ion cooling process. The data will arrive at the RHIC ion circulation frequency of 78 kHz. The overlap (alignment) of the electron beam with the ion beam will be crucial for ion cooling. Dipole trajectory correctors were discussed as a means to align the two beams. The power of the electron beam is about 1.7 kW which must be handled with a degree of care so as not to damage equipment. However it is not so high as to be big problem.

Comments

The electron beam size varies along the undulator length. These beam size changes should be put into the expected ion-electron beam interactions and, thus, into the cooling calculations.

The primary beam signals and specific measurements that will be used to prove ion cooling should be identified.

Full beam simulations with the expected actual beam geometry and magnets are needed to make sure the needed diagnostic resolutions are available for the primary cooling signals.

Recommendations:

- Review the measurement of the small beam energy spread to make sure the needed resolution and ease of use are available at turn-on.
- Review the measurement procedure of the absolute electron and hadron beam energies to make sure all known systematic errors at the 1 part in 1000 level are accounted for.
- Specify, measure and understand the various timing jitters among different RF, diagnostic and laser systems and the hadron bunch.

16. *CeC: e-gun Commissioning and Final System Commissioning Plan*

Findings

The RHIC beam parameters for the CeC PoP experiment have been analyzed and found acceptable. The commissioning of the equipment installed so far has been started and is approaching the final stage. The SRF gun and 500 MHz warm buncher cavities have been installed on the beam line. Cathode attachment to the SRF gun cavity has been demonstrated. To reduce risk, the injector for the CeC PoP experiment will be commissioned during Run 15.

Diagnostics equipment is being developed to improve performance (dual beam BPMs and beam charge monitors).

The final commissioning and tests will be performed during Run 16.

Comments

The committee appreciated the tour of the facility. The attachment system of the SRF gun cathode is very impressive. The committee has not yet clearly understood the space and labor compatibility with respect to the LEReC preparation.

Recommendations

None

Members of the Machine Advisory Committee

John Jowett, CERN (Chair)
S.Y.Lee, Indiana Univ. – *excused*
Sergei Nagaitsev, FNAL – *new member*
George Neil, JLab – *excused*
Kenji Saito, MSU
John Seeman, SLAC – *new member*
Peter Spiller, GSI
Richard Talman, Cornell

Observers attending this meeting

Lloyd Nelson (DOE)
Michelle Shinn (DOE)

Agenda

https://indico.bnl.gov/conferenceDisplay.py?confId=898

Monday, December 8, 2014

08:30 Executive Session
09:00 Welcome, Thomas Roser (BNL)
09:05 Response to Last MAC's Recommendations, Vadim Ptitsyn (BNL)
09:40 RHIC Status and Run Plans, Ultimate Au+Au Luminosity, Wolfram Fischer (BNL)

Low-Energy RHIC electron Cooling (LEReC)
10:40 LEReC Overview - Goals and Cooling Approach, Alexei Fedotov (BNL)
11:25 SRF Gun Commissioning Progress 20', Wencan Xu (CAD)
11:45 Beam Dynamics Simulations with DC Gun, Jorg kewisch (BNL)

13:00 Tour IR2 - Location of LEReC and CeC PoP
14:30 System Engineering Design, Construction, and Installation, Joseph Tuozzolo (BNL)
15:10 SRF and Warm RF Components, Sergey Belomestnykh (BNL)
15:40 Instrumentation, David Gassner (BNL), Toby Miller (BNL)

Coherent electron Cooling Proof-of-Principle (CeC PoP)
16:30 CeC Overview, Vladimir Litvinenko (BNL and Stony Brook University)
17:00 CeC Photo-Injector, John Skaritka (BNL)
17:30 Executive Session / Requests for additional presentations

Tuesday, December 9, 2014

08:30 Executive Session / Discussion

Coherent electron Cooling Proof-of-Principle (cont.)
09:00 CeC Overview of Construction Progress, Final Installation Planning, Joseph Tuozzolo (BNL)
09:30 CeC Theory/Simulations, Gang Wang (BNL)
10:00 CeC SRF and Warm RF Components, Sergey Belomestnykh (BNL)
11:00 CeC Diagnostics, Toby Miller (BNL), David Gassner (BNL)
11:30 e-gun Commissioning and Final System Commissioning Plan, Igor Pinayev (BNL)
13:00 Additional Requested Presentations
14:30 Executive Session and Report Writing

Wednesday, December 10, 2014

08:30 Executive Session and Report Writing
13:00 Closeout